

Sand consolidation via latex destabilisation

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Abstract

This article investigates the use of a commercial latex dispersion for the purpose of sand consolidation in oil wells. The aim is to consolidate sand without compromising permeability and to prevent sanding during water breakthrough. This is achieved by injecting latex dispersions into a sand-pack and relying on potassium chloride flushes, or irreducible saline water in the reservoir, to destabilise the latex onto the sand surface. This forms a latex network connecting and holding the sand grains together. The strength of the consolidation in the laboratory is determined by flowing water and oil at various flowrates and investigating the amount of sand produced. The effect of different parameters, such as the amount of latex injected, the latex salinity and salinity of the irreducible water are discussed.

Keywords: Latex, Sand consolidation, Single treatment, Sanding.

Introduction

Sanding in oil wells is a major problem¹. It usually occurs during water breakthrough, when capillary forces holding the unconsolidated sand grains together disappear because of the presence of bulk water. The water disrupts the cohesion between sand grains causing free grains to be released and carried into the production system. Sand production threatens a well in various ways². Equipment could start to lose mechanical integrity, or wells could cease to flow due to sand plugging the wellbore or production tubing.

Currently, sanding is controlled either mechanically or chemically. One of the most popular mechanical methods involves gravel packs⁴. These are comprised of an annulus created by inserting a metal screen into the wellbore, which is then packed with gravel of specific size, chosen to retain the formation sand.⁵ The screen holds the gravel in place and allows the produced fluids to flow into the wellbore. One of the drawbacks with the method is that the gravel pack or screen can become gradually plugged by fine solids, such as clays, during production. Another issue is that the screen can become damaged during installation or may be eroded later, during production, leading to failure of the system, and the production of sand. Repairing the screen and gravel can be an expensive operation.

A chemical method sometimes used is to inject resin to control sand. The sand grains are locked in a matrix using epoxy, furan or phenolic resins⁶. The degree of consolidation is not easy to control, and rock permeability can be readily damaged. Consequently, it is difficult to treat long sections evenly and it is common to observe loose sand arising from an uneven treatment. To achieve polymerisation of the resin, a shut-in time of several hours may be required for the resin to cure, during which time the treatment may have migrated away from the target zone.

There are variations on the chemical approach. For example, some novel commercial products utilise the negative surface charge of sand to control sand production^{1,7}. By controlling the surface charge, the interaction between grains can be controlled and this sets the sanding rate.

Here we investigate the use of commercially available latex to consolidate sand. The latex destabilisation method is, in principle, a cheap and simple way of preventing sand production. Latex dispersions are available with a vast array of sizes. By using particles of about 300 nm in diameter, the dispersions can flow into sand formations with ease. As the latex surrounds

the sand grains, its stability may alter or could be made to alter, e.g. by a change in the salinity environment. As the latex destabilises, the particles aggregate, fuse and coat the sand surface, forming a polymer network holding neighbouring sand grains together. However, as with all chemical treatment methods, the pore spaces are being filled with additional material and hence some permeability damage is unavoidable.

As far as the authors are aware, there are no scientific papers on sand consolidation using latex. There is a 1986 patent from Texaco Inc. which employs latex and relies on ester hydrolyses to reduce the pH and destabilise the latex dispersion⁸.

In this work we explore the idea of polymer rings between sand grains to hold them together. This is sketched in Figure 1 and can be applied analogously to the adhesion strength model of Rabinovich³. Upon water breakthrough, capillary rings will diminish but polymer rings remain unaltered. The result is a cohesive strength to the sand-pack that is unaltered by an aqueous or organic fluid.

This article explores destabilisation in two ways:

(1) Multi-stage treatment

Destabilisation is caused by multiple alternating injections of potassium chloride and latex into the sand-pack.

(2) Single-stage treatment

A latex dispersion which has been pre-salted with potassium chloride so that it is stable, yet close to the point of agglomeration, is injected into the sand-pack. Latex destabilisation is dependent on the salinity of irreducible fluid in the sand-pack, also known as connate water.

As well as exploring the effects of potassium chloride, the rate and agglomeration behaviour of the latex with sodium chloride and pH will also be briefly discussed.

Materials and Method

Materials

The latex dispersion (Synthomer X6311) was obtained from Synthomer. It is an aqueous, colloidal dispersion of carboxylated butadiene-acrylonitrile copolymer. The dispersion contains an emulsifier system and is stabilised with an antioxidant. Its physical properties, from the Synthomer data sheet, are shown in Table 1. The sanding tests used extra pure Ottawa Sand (Mesh size 20-30, Fisher Scientific). The electrolytes were either potassium or sodium chloride (Reagent Plus >99.0%, Fisher Scientific) and they were typically dissolved in ultrapure water (Resistivity 18.2 MΩ cm, Elga Waters). For the oil Clairsol 370 (Haltermann Carless), an aliphatic oil and a simple model for crude was employed.

Method

Sand packing and glass cell

Sanding tests were performed in a custom made glass cell, blown according to our design by Soham Scientific. The dimensions of the cell are given in Figure 2. The glass cell was filled with tap water and then a known mass of sand was gradually added, keeping the injector (inlet) and producer (outlet) plugged.

Once the desired packing height was achieved, the water was displaced by pouring Clairsol 370 oil slowly from the top and draining the water by gravity via the injector. Care was taken to ensure the sand-pack stayed submerged in liquid during this displacement process. With the water displaced, a vacuum seal was put on top of the glass cell. A good vacuum seal holds the liquid in place when the producer is opened. Note that after displacement with oil, the sand still retains some water, in the form of irreducible or ‘connate’ water which exists as a water layer around the hydrophilic sand grains. The pipe and pump connections, for treatment and production, are given in Figure 3. Treatment is injected into the ‘producer’, simulating how it would be injected into perforations in the field. Sanding tests are then performed by

injecting either oil or water into the injector port to produce a flow from the producer, and observing whether sand is produced.

A small number of sanding tests were also conducted in a high pressure sand rig with temperature control for both single and multiple-treatments. This more sophisticated sand rig (not shown) allowed testing using tighter sand-packs with permeabilities as low as 300 mD at 50°C.

Potassium chloride salinity requirements

To determine the salinity required to achieve destabilisation. 25 ml glass vials were filled with 5 g of sand before adding 15 ml of potassium chloride solutions at various concentrations. 2.5 g of latex was added and the entire vial vortexed for 20 seconds and then left at room temperature. Any physical changes to the latex were observed with time.

Multiple-stage treatment

The multiple-stage treatment was achieved by alternately injecting salt solution and latex dispersions 4-5 times, with 15 minutes intervals in-between. The total time for injection was of the order of 2 hours. By doing this, mixing was induced within the sand-pack during injections and latex destabilisation was achieved. Figure 4 gives a sketch of the various steps.

Various latex dispersion concentrations and salt concentrations were experimented with and any signs of sanding were recorded.

Single-stage treatment

The single-stage treatment was done by substituting the tap water, used during sand packing, with saline water. This introduced a saline connate fluid into the well. In addition, the latex was pre-mixed with a potassium chloride solution. This was referred to as 'pre-salting' the latex, pushing it towards the edge of destabilisation, but ensuring it remained stable upon

injection. The mixing of the pre-salted latex and connate fluid in the sand-pack caused destabilisation and hence consolidation.

Sanding test

After a single or multi-stage treatment, sanding tests were conducted. Tap water or Clairsol 370 was flowed through the injector and any sand produced was collected at the producer. The fluid flowrates were varied from 0.1 to 2.0 g/s in small increments, allowing at least a litre of fluid to be collected at each flow-rate. It was normal to observe some negligible sanding (countable number of grains produced) during flowrate changes. An increase in flowrate created a shock to the sand-pack and hence disrupted the sand agglomerates. The consolidated pack was also left overnight and sanding tests were repeated in the next 2 days to check the stability of the latex network soaked in water and Clairsol 370.

Strength Testing

Mechanical tensile testing was done to explore the consolidation strength with different latex concentrations. For these tests 68 g of sand (0.4-0.8 mm diameter particle size) was transferred into a 50 ml beaker and completely wetted with 25 ml of 10 wt% KCl. Then 20 ml of latex was injected into the sand-pack via four injections, each of 5 ml. The sand became consolidated and cylindrical sand-pack samples, 5 cm in diameter and about 5 cm in height, were carefully removed from the beaker and loaded onto a Hounsfield low load electric screw machine. The samples were glued onto the upper plate and the consolidated sand was sufficiently robust to be able to withstand this entire operation. A tensile force was then measured, at a vertical displacement of about 1 mm per minute. Failure occurred within the sand structure, not at the glued sand – plate interface. Therefore we are happy to report the measured failure stress as a property of the consolidated sand. The experiment consisted of investigating a range of latex concentrations.

Results and Discussion

Potassium chloride requirement for destabilisation

For a pH of 6, at KCl concentrations above 5 wt%, latex destabilisation was almost instantaneous (less than 20 minutes for 5 wt% and progressively quicker with increasing salinity). The result was a solid lump of coagulated polymer at the bottom of the container. At salt concentrations below 3.3 wt % KCl the latex was stable for at least 8 days. For intermediate concentrations the destabilisation process was slow and dependent on the salt concentration.

With the addition of salt, the zeta potential of the latex dispersion was altered due to charge screening, by the cations, of the negatively charged latex surface. It should be noted that this critical coagulation concentration is dependent on the valence of electrolyte used and can be predicted with DLVO theory⁹⁻¹¹.

Multi-stage treatment

With the multi-stage treatment, sand consolidation was successful for almost all cases, as shown in Table 2. This demonstrates the validity of using polymer rings to consolidate sand. For the test with 7.5 wt% latex and 10 wt% KCl, plugging was observed at the producer side and this was likely caused by instantaneous agglomeration of the latex in the pipelines, when in contact with the high concentration of KCl. An over pressure in the glass cell resulted in the top seal leaking fluid as the fluid preferred to flow through the covered top, rather than through the producer outlet during the sanding test.

The lower salinity brine solution was more beneficial because we could avoid the possibility of plugging the pipelines and over-treating the sand-pack, particularly at the producer side. However, at salt concentrations below 6 wt% KCl the sand consolidation became insufficient to prevent sanding during water flow. We would expect the latex dispersion to aggregate

quickly with 5.0 wt% KCl, as shown from the destabilisation vial tests, but this was not observed in the sanding rig. A possible reason could be that the latex and KCl were injected as plugs with the same flow rate. If both solutions were perfectly mixed, the total KCl concentration would be half of its original value. However, this is the simplest mixing scenario and a better understanding on how the two fluids mixed in the porous media would provide valuable information on the latex aggregation behaviour.

Experiments using the high pressure sanding rig with temperature control were carried out. Table 3 shows that a tight sand-pack (300 mD permeability) exhibited permeability damage of 65% after a single treatment. The relatively low permeability caused high pressure drops during the subsequent sanding test, such that the sample failed at a water flow rate of 40ml/minute (at 48 bar pressure). The looser sand-pack, with a permeability of 2500 mD, showed only 40% permeability damage after multiple treatments and produced minimal sanding.

Single-stage treatment

Level of pre-salting required

The stability tests indicated that a salinity of around 3.8 wt% KCl would be ideal to alter the latex from a stable or slowly aggregating dispersion, to an unstable dispersion with quick aggregation. This slow to quick aggregation transition was the driving force for the instantaneous consolidation of the sand-pack. The level of pre-salt salinity was decided by the flow time needed for the fairly stable latex to reach the targeted sand-pack. For example, latex pre-salted with 3.8 wt% KCl would only be used if the flow path is less than 2 hours. If it was any longer, blockages would be seen along the pipe lines. Higher pre-salted latex was also preferred as it would give a better chance of consolidation with saline connate waters.

A simple experiment was done with 25 ml glass vials containing 5 g of sand which were pre-wetted with 15 ml of various aqueous formation fluid compositions, as shown in Table 4. The formation fluids were then removed via tipping the vial to drain most of the salt solution or with a syringe. Both methods allowed a certain amount of formation fluid to remain in the sand. 15 ml of 5 wt % latex with 3.3 wt% KCl was then pipetted into each vial, making sure the latex got into first contact with the pre-wetted sand. Any signs of consolidation within the sand-pack were then recorded.

Four different formation fluids were investigated, with total electrolyte compositions shown in Table 4. Since the Debye lengths of all the formation fluids were well below 0.41nm, one would expect fast latex aggregation from them all. Representative images of the sand, latex, salt solution mixtures are shown in Figure 5. Sand consolidation was seen for all formation fluids apart from fluid 1, (Figure 5a), which was surprising. Possibly, upon mixing the total ionic concentration of the aqueous phase with latex was insufficient.

Single stage treatment of sand-packs

After establishing the level of pre-salting required, sanding experiments were conducted in the glass cell with the formation fluids (results not shown). Only one injection of 150 g of 10 wt% latex, pre-salted with 3.3 wt% KCl was used for this initial screening, at a flowrate of 3.4 ml/min. There was no shut-in time for these sanding tests. Successful consolidation was seen for the high salinity fluids 3 and 4. Formation fluid 2 showed some consolidation with signs of some latex linking the sand grains together but the effect was only weak (sanding occurred during 0.67 ml/min water flow) compared to fluid 3 and 4 (no sanding seen up to 120 ml/min water flow). One explanation could be that only a small amount of connate fluid (formation fluid) is within the sand-pack, as most of it had been displaced by Clairsol 370.

Consequently, for the lower salinity formation fluid 2, only a small proportion of the injected latex was destabilised and this was insufficient to prevent sanding.

With some promising results from the glass cell, additional experiments were performed using the high pressure sand rig. Sand consolidation with high salinity connate fluid was again observed -see Table 5. With formation fluid 3 as the connate fluid, the effect of the number of pore volumes (PV) of latex injected on permeability retention of the sand-pack was investigated. Unsurprisingly, a larger latex injection induced higher permeability damage. One PV of latex was not enough to consolidate the sand-pack, as complete sanding was seen with deionised water at 40ml/min. Insufficient consolidation was also seen with 3 PV of latex pre-salted at 3.7 wt% KCl using formation 4 connate water. It was interesting to observe that a higher pre-salting latex (3.7 wt% KCl) and 3 PV of treatment was still inadequate to consolidate the sand. Shut-in time played a key role as drastic permeability damage from 11.3 to 68.0% was seen when 2 hours shut-in time was introduced. The effect of shut-in time becomes more prominent when the latex has a marginal stability and significant time will cause aggregation and hence consolidation as well as permeability damage

Table 5 is encouraging in that the tests with 686 and 1680 mD sand-packs were successful in achieving complete consolidation with no sanding. However these two experiments did demonstrate significant permeability damage. Further work to balance consolidation and no sanding with limitation of permeability damage is required. Further experiments were done to investigate the possibility of consolidating sand-packs with low connate fluid salinity, i.e. a Debye length of more than 0.15 nm. This was to limit permeability damage. Shut-in times ranging from about 2 hours to 28 hours were introduced after latex injection. Shut-in was vital as experiments with 4, 6 and 8 wt% NaCl, showed signs of destabilisation but not enough to consolidate the sand. The pre-salt concentration in the latex dispersion was also

increased from 3.3 to 3.7 or 3.8 wt % KCl. With such high pre-salt concentrations, quick handling was imperative as the latex dispersion were only stable for up to 2 hours. With 3.7 wt% KCl in latex, sand-packs with connate fluid salinity of 8 and 10 wt% NaCl were consolidated as long as shut-in times of about 24 hours were incorporated. Connate fluid of 6 wt% NaCl was partially consolidated as sanding only occurred at water flow rates of 100 g/min. When both sand-packs were removed, it was noticeable that the sand-pack with less saline connate fluid was more loosely consolidated, when compared to the more saline connate fluid. To eliminate shut-in times, 3.8 wt% KCl in latex was tested with a 10 wt% NaCl sand-pack. However, it was observed that the sand-pack was over-treated and water started to leak through the top seal. This was undesirable as significant permeability damage had been caused to the sand-pack itself due to the quick aggregation of the latex. We conclude that it is challenging to get the right balance between initial latex salting, shut-in time and latex concentration as a function of the connate salinity. It should be noted that the high pressure tests were performed at 50 °C whilst the tests in the glass flow-cell were performed at room temperature, approximately 25 °C.

Strength Testing

The amount of latex deployed affected the consolidated strength of the sand-pack. Higher amounts of latex created a stronger sand-pack and this could be observed when the sand was removed from the glass cell and scraped with a spatula. Mechanical tensile testing with various latex concentrations, destabilised with 10 wt% KCl demonstrates this quantitatively. Figure 6 shows the stress – displacement curve for sand consolidated with 5 wt% latex. The horizontal axis is displacement rather than strain since the sample height is not accurately known. The stress-displacement curve shows a definitive maximum, which corresponds to the failure stress. This is reported in Figure 7 for various latex concentrations and it can be seen that the failure stress increases as the latex concentration is increased. It should be noted

that the reported failure stress is the stress that led to rupture of the consolidated sand, not the fixing between the sand and support.

Optimum Dispersion Design

Using the results from this work, it is interesting to speculate as to the optimum latex properties to achieve sand consolidation. The design parameters are likely to be particle size, particle charge and polymer composition.

Particle Size

The latex particle size is needed to be small enough so that it flows readily into the sand. Most commercially available latex is around 200 - 300 nm in diameter, although smaller particles can be obtained at higher cost. Smaller particles are likely to form polymer rings more quickly, although the formation time of polymer rings seems to be fast relative to the shut in and flow times down well and is therefore not an issue. Other complications may arise with smaller particles forming too thin a polymer ring to provide effective consolidation, although more work is needed to investigate this. Consequently we speculate that the latex particle size needs to be considerably smaller than the sand pore size, but otherwise the size is unlikely to be important.

Particle Charge

The particles used in this study were anionic, due to the presence of initiator moieties on the particle surface. The sand is also anionic, resulting in the suggestion that the latex particles will be repelled from the sand. The electrolyte concentration of connate water is sufficiently high to destabilise the latex particles. This means that electrostatic repulsion is not sufficient to keep particles and sand grains apart. The speculation is therefore that the charge on the latex surface does not play a dominant role in determining its effectiveness at sand consolidation.

Polymer Composition

A necessary design criterion is that the destabilised latex must form rings around the sand grains. This means that the surface energy between latex and sand should be less than the latex-water surface energy. The exact calculation is complex, since it depends on surface area and hence sand grain topology. We can however say that the polymer must be hydrophobic, so that it is energetically favourable to stick to the sand. This suggests the use of butadiene polymers, such as in this study, or acrylic polymers such as polystyrene and polyacrylates. The *exact* composition must be chosen so that the glass transition temperature of the polymer is considerably lower than the well temperature, allowing consolidation of the destabilised latex to readily occur.

Conclusion

Sand consolidation by destabilising latex particles can be achieved in principle, although controlling the process would appear to be challenging. The strength of consolidation depends on the amount of injected latex and a high enough salinity is needed to destabilise the latex in-situ. The destabilisation could be triggered in the field by alternately injecting a salt solution, such as potassium chloride solution, and a latex dispersion in multiple injections until the desired consolidation strength is obtained. However, to avoid multiple injections, which would not be very practical, we have explored the possibility of pre-salting the latex so as to apply a single treatment. Reservoirs are naturally saline and so we can consider using the connate water itself to destabilise the pre-salted latex. The latex would be pre-salted, for example, using potassium chloride and then injected into the weak sand in a single stage. As a variation, the latex and salt solution could be co-mingled by pumping the two fluids simultaneously into the well at appropriate rates to create the required composition. Controlling the consolidation process could be difficult because of natural variations such as rock permeability, connate water composition, pH and temperature, but this study

demonstrated the concept and showed a consolidation effect could be observed in the laboratory. Clean sand was used in the experiments but in practice it may be necessary to first pump a pre-flush (e.g. salt solution, surfactant or solvent) to remove contamination in the tubing or within the rock. Further development work is needed to produce a practical system, including investigating a range of latex types to find a formulation with the optimum characteristics. The latex needs to trigger under a range of field conditions to create sand consolidation, at the same time avoiding excessive permeability damage. For low salinity reservoirs, the work suggests it would be necessary to incorporate significant shut-in times, as the aggregation process is slow and requires time to achieve acceptable consolidation strength.

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